Optimization of a Metallo-Dielectric EBG Waveguide

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Introduction

Bragg fibers have demonstrated to be very low loss in the infrared (IR) band [1]. They consist of cylindrically periodic layers surrounding an air core (Fig. 1a). The periodicity is realized by employing two different dielectrics, one with high and one with low permittivity. These structures propagate a leaky wave mode whose radiation is minimized by using both a large number of periods (typically 15 or more) and a large difference in relative permittivity (10 or more). However, successful IR Cylindrically Periodic Waveguides (CPWGs) have been fabricated using a large number of layers and high dielectric constant low-loss materials that are not available, at the present time in submillimeter wave band .

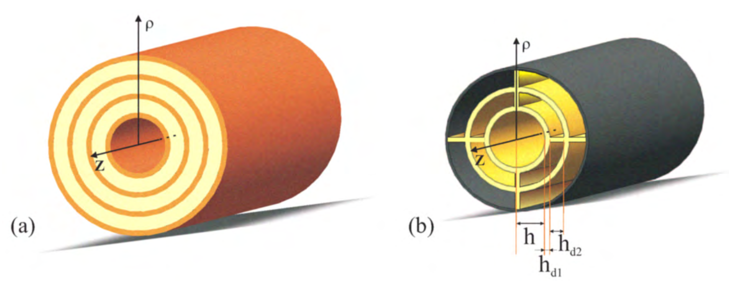

Figure 1: Geometry of a CPWG: (a) all dielectric and (b) new metallo-dielectric geometries.

In this paper we describe an alternative CPWG with a small number of layers (air-fused quartz) that is terminated by a metal wall. This wall adds a modest conductor loss contribution but eliminates the radiation that would otherwise dominate. The proposed CPWG (Fig. 1b) works on the low loss TE_{01} mode. In a Bragg Fiber (open structure) the optimal dielectric thicknesses realize the same "resonant condition" of planar leaky wave antennas [2] which creates a null in the tangential electric field at the start of each period. If a metallic boundary is placed at any of these points, one would expect that the mode properties are not significantly altered. A CPWG whose dimensions are defined by this condition will propagate a TE_{01} and a EH_{11} with the same propagation constant [3]. The degeneracy between these modes makes the coupling between the two modes along bends independent of the waveguide radius [4]. It is now possible to reduce the mode coupling along a bend by breaking this degeneracy. To do this we can equivalently introduce a ρ–transmission line to describe the transverse resonance of the field, and a ϕ–transmission line to take into account for the dielectric posts that space out the dielectric cylinders.

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Structure Optimization

Two different kinds of optimization can be performed and in case combined: optimization of the thickness of radial dielectric layers (ρ-transmission line) or optimization of the number and thickness of dielectric azimuthal posts (ϕ-transmission line). For sake of simplicity, we present the results obtained for a CPWG with only one period air-quartz ($\epsilon_r = 4$). These results are already quite promising, and in practical applications, one would use at least two periods to further reduce the propagation losses. As a matter of the fact, while the dielectric losses are mostly determined by the first dielectric interface [5], the conductor losses are reduced increasing the number of layers.

ρ - Transmission Line

Concerning the dielectric thickness, the CPWG structure can be optimized as described in [3] where it has been found that the dimensions $h = 326\mu$m, $h_{d1} = 62\mu$m and $h_{d2} = 187\mu$m are optimum for propagating in radius $R > 18\lambda$ at 750GHz. Figure 2a shows the propagation constants of the optimized structure, calculated by using the procedure described in [5] and the data simulated with CST Microwave Studio^{TM}. Starting from these propagation constants it is possible to calculate the quantity $\Delta\beta = \beta_{TE_{01}} - \beta_{EH_{11}}$ that, by using $R = \frac{4.64h}{\Delta\beta\lambda_0}$ allows us to find the bend curvature radius R that introduces a loss of a 1dB [4]. Fig. 2b shows this radius R versus frequency. Finally, the dielectric losses (calculated assuming $tan\delta = 2 \cdot 10^{-4}$ for the fuse quartz dielectric) are shown in Fig. 3a.

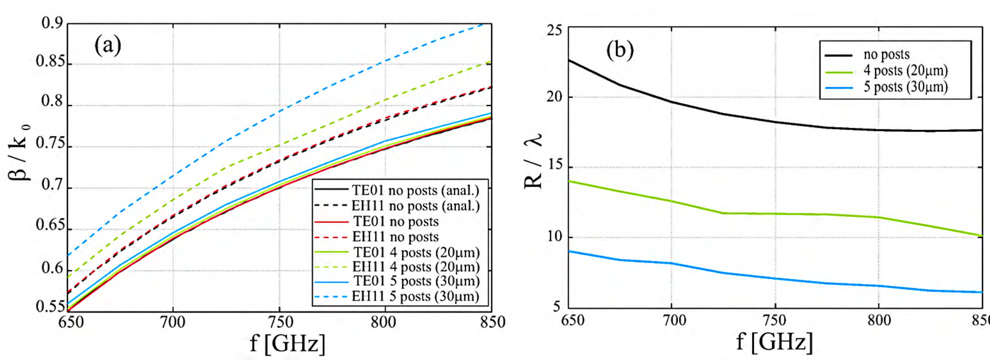

Figure 2: (a) Propagation constants for the optimized CPWG without posts (analytical and simulated with CST) and with four 20μm thick posts or five 30μm thick posts; (b) bend radius, normalized to the wavelength, associated to 1dB loss.

ϕ - Transmission Line

Possible fabrication methods of such a CPWG will make use of thin radial small supports between the dielectric layers. Calculations show that these supports do not alter significantly the TE_{01} propagation constant (see Fig. 2a) and reinforce the removal of the degeneracy of the TE_{01} and EH_{11}, even though increasing the dielectric losses. Thus, the presence of the supporting posts allows us to have a lower bend loss by a equal bend curvature or, equivalently, to have a smaller curvature radius R for the same $1dB$ bend loss (see Fig. 3b). Figure 2 compares the propagation constant and bend radiuses of the optimized CPWG, without and with different posts configurations. As an example, Fig. 3b shows the electric field at 750GHz for the five posts configuration. We can see that the field increases nearby to the posts, introducing a slightly higher dielectric loss (see Fig. 3a). The conductor loss is not significantly altered by the presence of the posts.

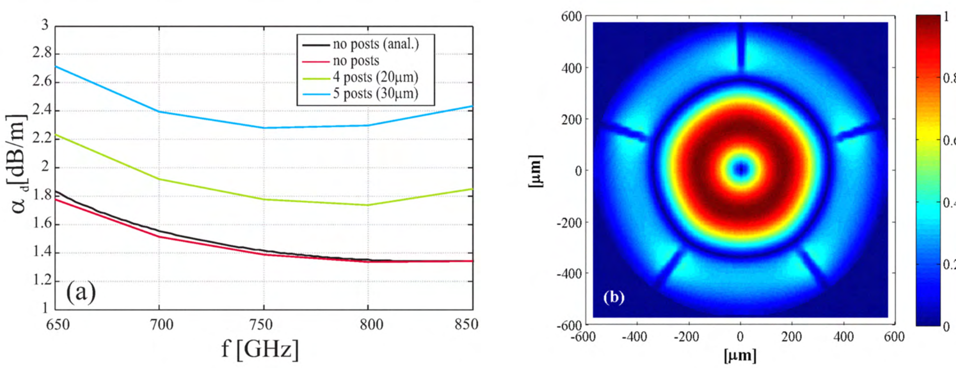

Figure 3: (a) Dielectric loss. (b) TE_{01} electric field distribution at 750GHz for the structure with five posts.

Bend Loss

In this section we consider the bend loss behavior of the optimized CPWG, with and without azimuthal posts. As explained in [4] the coupling between the TE_{01} and TM_{11} modes of a CWG depends only on the bend angle, but not on its radius. This angle is associated to the length of uniform coupled transmission lines. Therefore the coupling will have minima and maxima depending on this length. If the degeneracy between the modes is broken, thus they do not propagate at the same phase velocity, the coupling will then depend on the bend radius. Although this coupling will still be periodic depending on the bend angle, the maximum energy transferred to the EH_{11} mode will be reduced as a function of $\Delta\beta$. The extinction angle, where maximum transfer occurs, is also altered with $\Delta\beta$.

In order to validate our design optimization, we simulated several curved structures with CST. We considered a 90^o bend having a radius of 6mm. Figure 4a shows the simulated S_{12} parameters for the resonant structure and for the optimized one, with and without posts. In Fig. 4 are also shown the maximum losses related to the obtained $\Delta\beta$ calculated from the curve given in [4]. Notice that the actual loss will be between this maximum and 0dB (depending on the bend angle and core dimensions). Figure 4b and 4c show the simulated electric field distributions of the resonant and optimized CPWGs, respectively.

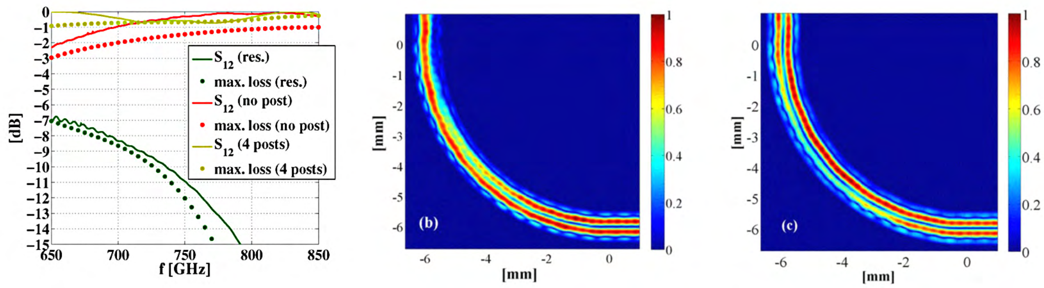

Figure 4: Full wave simulations of a 6mm bend: (a) S_{12} parameter and maximum losses; (b) and (c) electric field distributions of the resonant and optimized CPWGs, respectively at 750GHz.

Conclusions

In this contribution we have presented a new metallo-dielectric EBG waveguide. The initial concept is based on Bragg fiber, which cross section is usually very large in terms of the wavelength. To reduce the waveguide dimensions and make it feasible at THz frequencies, we use a combination of a metallic and a dielectric waveguide. Standard resonant geometries will have high bend coupling between the TE_{01} and EH_{11} modes, thus reducing the losses introduced by the bend. Here we present two ways of optimizing the waveguide structure to break the degeneracy between these modes. One considers the periodicity along ρ and the other along ϕ. The results can be extended to structures with two or three periods to reduce the metallic losses. These structures will have an overall propagation and bend loss lower than an overmoded circular waveguide working on the TE_{11} mode.

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